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A Lab to STEMulate Undergraduate Students into Science, Technology, Engineering and Mathematics Majors

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A LAB TO **STEM**ULATE UNDERGRADUATE STUDENTS INTO **S**CIENCE, **T**ECHNOLOGY, **E**NGINEERING, AND **M**ATHEMATICS MAJORS

A thesis submitted in partial fulfillment
of the requirements for the degree of
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By

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Nicole Lynn Speelman ENTITLED A Lab to **STEM**ulate Undergraduate Students into **S**cience, **T**echnology, **E**ngineering and **M**athematics Majors BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

Speelman, Nicole Lynn. M.S., Department of Chemistry, Wright State University, 2009. A Lab to **STEM**ulate Undergraduate Students into **S**cience, **T**echnology, **E**ngineering and **M**athematics Majors.

The central focus is the development and implementation of a research/lab module for first year chemistry courses. Electrochemical techniques are utilized to study oxidation and reduction reactions of neurotransmitters with a poly(2,2'-Bithiophene) modified electrode. The goal is to excite students about chemistry and encourage them to continue studies in Science, Technology, Engineering, and Mathematics (STEM) during their undergraduate education. The lab module was created for Project REEL (Research Experiences to Enhance Learning) and will be illustrated with results typically obtained by students. The experiment is inquiry-based, which includes challenging questions students have to do collaboration and research to answer, as opposed to a traditional step-by-step lab. The effectiveness of the lab is assessed with pre/post-tests and a survey response. Analysis of the pre/post-test scores indicates the students' content gain was high. Overall, the students responded positively to their experience with this innovative lab module.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

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I. INTRODUCTION

Electrochemical techniques are rarely studied in undergraduate chemistry courses and students are not usually exposed to scientific research opportunities at this time in their college education either. The goal of this research was the development and implementation of an inquiry-based lab module for a first year chemistry course. The lab module involves the study of oxidation and reduction reactions of neurotransmitters in the presence of an interferent utilizing cyclic voltammetry. Basic electrochemistry, educational strategies, and the REEL Project will be addressed.

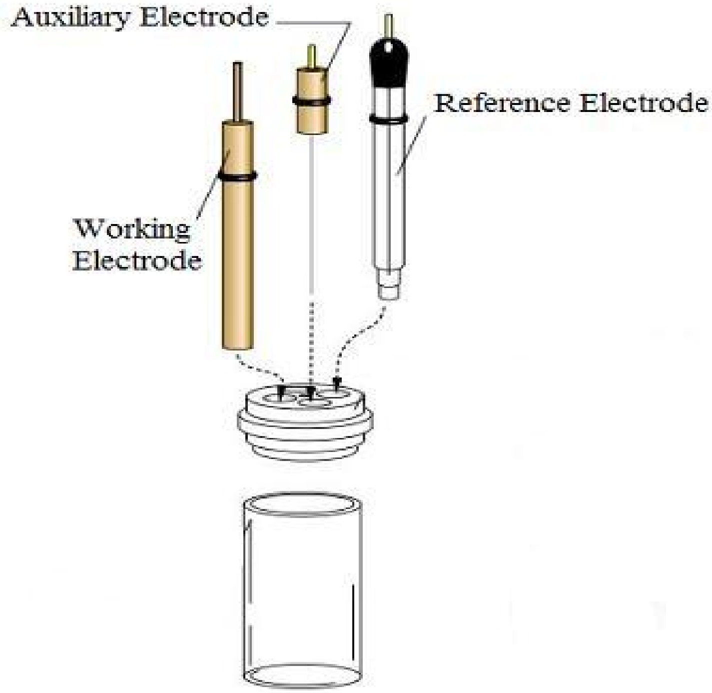
A. THEORY OF ELECTROCHEMISTRY

1. Electrochemical Parameters

Electrochemistry is the study of chemical reactions that undergo oxidation and reduction. Oxidation occurs by removal of one or more electrons from an atom or molecule and an increase in positive charge. Reduction happens when an atom or molecule gains one or more electrons coinciding with a decrease in charge.

The system in which electrochemical reactions take place is the electrochemical cell. (Figure 1)

Figure 1. Diagram of a single compartment three electrode electrochemical cell.



The potential difference existing between the electrode and the solution is controlled or measured during an electrochemical reaction. Without a current, a potential gradient does not occur across the bulk solution meaning that an ion or molecule has no chemical interaction with the electrode. The working electrode is platinum or glassy carbon, the reference electrode is Ag/AgCl, and the auxiliary electrode is a platinum wire. The working electrode is where the electrochemical reaction occurs. The auxiliary electrode completes the circuit in order for charge to flow through the cell. The reference electrode maintains a constant potential difference independent of the current. The electrochemical cell is connected to a potentiostat which controls the applied potential and measures the resulting current from the reaction.

Placing an electrode in a solution creates two distinct types of molecules, those at a distance from the electrode and those molecules close enough to interact with it. Creating a phase boundary within the solution is pertinent to the bulk-phase properties of a solution. The movement of material from the bulk liquid phase to the electrode surface in an electrochemical cell is referred to as mass transport. Mass transport can happen in one of three ways: hydrodynamics, migration, or diffusion. Hydrodynamic transport happens by stirring, rotating an electrode or flowing solution through a cell. Migration occurs by molecules interacting with an electric field that exists near the electrode. The simplest and best understood is diffusion [1, p 12].

For diffusion to occur, in a closed, isotropic system a single molecule continually collides with neighboring molecules in which there is no favored direction of motion. If an imaginary plane divides the system, net movement from one side to the other is zero. Equilibrium exists because the chemical potential is uniform. Mass transport occurs by diffusion when the chemical potential is no longer uniform and molecules move from a region of higher to lower chemical potential. This will maximize entropy. Flux is a measure of the rate of mass transport and is important because of its relationship to electrode current. As seen later, current depends upon the diffusion coefficient and concentration which are directly related to flux [1, p 13].

One or more phase boundaries, which can be permeable or impermeable, may exist in a solution that will affect diffusion. As in the case of electrochemistry, the electrode usually acts as an impermeable phase boundary. Sometimes the diffusion barrier is not passive but can interact with the solute via an electrochemical reaction. A semi-infinite diffusion is encountered in electrochemistry by either an impulse of molecules at the electrode surface in response to a change in potential, current, or charge. It can also occur by creating a vacancy in a layer of solution adjacent to the electrode by reducing or oxidizing the solute. Simple diffusion is a linear process so the total concentration profile will be described by a summation of the response functions (movement of the molecules) to the original excitation pulses (applied potential) [1, p 22-24].

Some useful equations to describe the diffusion process are Fick's Laws:

$$J_{x,t} = -D(dC_{x,t}/dx) \tag{1}$$

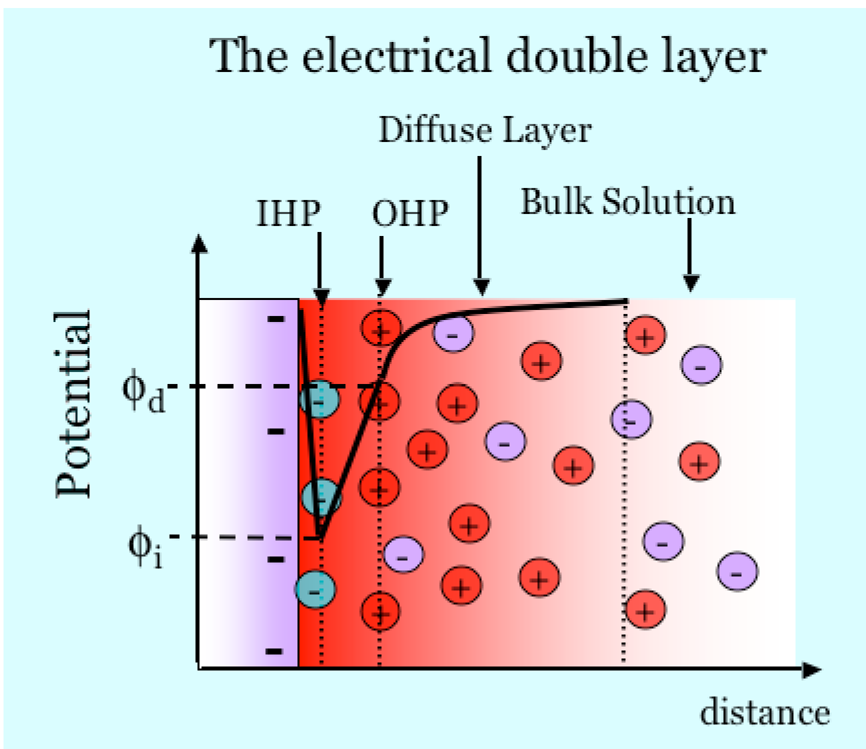
Where J is flux per unit area in mol/cm^{2}s, $D = (\Delta x)^2/2\ \Delta t$ (x is position and t is time), $(dC_{x,t}/dx)$ is the concentration gradient.

$$(dC_{x,t}/dx)_{x=x2} = D(d^2C_{x,t}/dx^2) \tag{2}$$

When the second partial derivative is equal to zero, the concentration is unchanging. When the second derivative is negative or positive, the concentration is decreasing or increasing respectively with time.

The electrical double layer is the region across which the potential difference exists and is where electrochemical reactions take place. Adsorbed molecules or ions are those in direct contact with the electrode and not completely solvated. The plane that passes through the center of these molecules is called the inner Helmholtz plane (IHP). The next layer of semi-solvated molecules is separated from the electrode by the monolayer of molecules on the electrode surface and that plane is known as the outer Helmholtz layer (OHP). On the outside of the OHP is the diffuse layer which is composed of ions determined by electrostatic interactions between the potential of the OHP and other ions and solvent molecules. Beyond the diffuse layer, ions in the bulk solution phase cannot feel the presence of the electrode. A Boltzmann distribution of charge exists in the diffuse layer [1, p 29-30]. (Figure 2)[2].

Figure 2. Diagram of the Electrical Double Layer



The potential for molecules in the IHP is φ_i and the potential for molecules in the OHP is φ_d as shown in Figure 2.

For a surface electron-transfer reaction that is rate-controlling and occurring at a single electrode with a fixed potential, where both O and R are soluble is:

$$O + ne^{-} \leftrightarrow R$$

O and R are the oxidized and reduced species respectively. The forward and backward heterogeneous rate constants, $k_{f,h}$ and $k_{b,h}$, are formal constants implying that the activity coefficients are unity. The formal rate constants are potential dependent.

Applying a potential will initiate the redox reaction and create a measurable current, known as the Faradaic current. The total current is the sum of the cathodic (reduction) and anodic (oxidation) reactions. Net current (i_{net}) depends both on the surface concentration of the redox couple and the potential, and is described by the Eyring equation:

$$i_{net} = nFAk_{s,h} \left[C_O e^{-\alpha nF(E-E°')/RT} - C_R e^{(1-\alpha)nF(E-E°')/RT} \right] \qquad (3)$$

Where n is the number of transferred electrons, F is Faraday's constant, A is a pre-exponential factor, $k_{s,h}$ is the heterogeneous rate constant, C_O and C_R are the concentrations for the oxidized and reduced species respectively, α is the transfer coefficient, E is the applied potential, E°' is the standard reduction potential for the redox couple, R is the gas constant, and T is the temperature.

At equilibrium, where [O] = [R], i_{net} becomes zero and the Nernst equation results.

$$E_{eq} = E°' + 2.303\ (RT/nF) \log [C_O/C_R] \qquad (4)$$

Most electrochemical techniques involve nonequilibrium conditions. In order for a Nernstian response to be exhibited, the rates must be very fast and equilibrium has to be reestablished at the electrode surface quickly [3].

Another important factor in electrochemistry is the overpotential. Overpotential is the difference between a half reaction's thermodynamically determined reduction potential and the potential at which the redox event is experimentally observed. It is described by the Butler-Volmer equation:

$$i_{net} = \underline{i}_0 A\ [e^{-\alpha nF\eta/RT} - e^{(1-\alpha)nF\eta/RT}] \tag{5}$$

Where $\underline{i}_0 = nFk_{s,h}C_O^{(1-\alpha)}C_R^{\alpha}$ (equations 3 and 4) and the overpotential is $\eta = E - E_{eq}$.

Two limits exist for the Butler-Volmer equation:

1) For small overpotentials ($\eta < 8$ mV/n), the current is directly proportional to the overpotential. Therefore, near the equilibrium potential an electrochemical reaction gives a linear current vs. potential curve.
2) For large overpotentials ($\eta > 120$ mV/n), the rate of one of the reactions becomes negligible. Thus, the current is logarithmically related to overpotential [1, p 37].

2. Voltammetry

Voltammetry is a common electrochemical method used to study redox reactions by measuring current. Stationary-electrode voltammetry involves an unstirred solution.

The scan is initiated at a potential E_i at which no reaction is taking place and then continuing through the standard electrode potential. Because the electrode is stationary, the diffusion layer will not be altered during electrolysis of the solute. The ratios of O and R that must exist at the electrode surface are determined by the Nernst equation for electrochemically reversible reactions [3].

Two important parameters for voltammetry are peak current, i_p, and peak potential, E_p. For reversible systems, the peak current (i_p) is defined by the Randles-Sevcik equation:

$$i_p = (2.69 \times 10^5)\, n^{3/2} A D^{1/2} C^\circ \nu^{1/2} \tag{6}$$

Where n is the number of electrons transferred, A is the electrode surface area, D is the diffusion coefficient of the species being reduced/oxidized, C° is the concentration of the respective species in the bulk solution, and ν is the scan rate (V/s) at 25 °C.

Peak potential (E_p) is defined for a reduction at 25 °C:

$$E_p = E^{\circ\prime}_{O,R} - 0.029/n \tag{7}$$

$D_O = D_R$ and $E^{\circ\prime}_{O,R}$ is the formal electrode potential corrected to the reference electrode being used.

Peak current increases with scan rate, but peak potential is not affected because the change in concentration is larger for a faster scan rate. The concentration ratio of the redox couple is determined by the Nernst equation which is independent of the scan rate [1, p 82].

For an irreversible system, the peak current and peak potential are affected by the scan rate. Thus, peak current is dependent on the number of electrons in the rate-determining step of the electrode process. The peak potential is influenced by the electron transfer reaction heterogeneous rate constant.

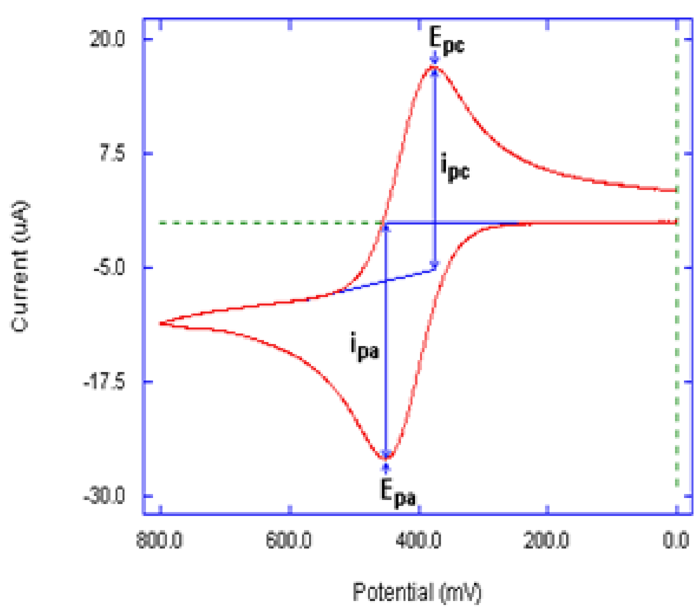
Another factor in voltammetry is the background current. The background current results from the solution containing everything but the species of interest. It is composed of residual current occurring via reduction or oxidation of any electroactive material present that is immaterial to the redox study. Also contributing to background current is the charging current which is the nonfaradaic current required to charge the electrode to a given potential. In order to find the true peak current, it is necessary to determine i_p by taking the difference between the baseline current and the faradaic current. The charging current at a given potential is directly proportional to the scan rate. Therefore, as the scan rate increases, the effect of the charging current on the background current becomes more significant [1, p 83].

Cyclic voltammetry is an electrochemical technique which scans electrode potentials rapidly and redox couples can be characterized from their peak potentials. If only O is initially present, R is obtained via reduction resulting in a cathodic current until [O] is effectively zero and is signaled by the peak potential. When [O]=[R], the observed potential is the formal electrode potential for the couple. As the reaction proceeds, O is depleted at the electrode until it is completely converted to R. The process continues with oxidation of R and an anodic current until [R] is negligible and is signaled by its peak potential. Once the cycle is complete, any number of scans can be run as reproducibility is important when studying electrode function with time [3].

A cyclic voltammogram (CV) is obtained by sweeping back and forth between two potentials for the working electrode. Those two potentials are called the switching potentials. A positive scan is one in which the potential is becoming increasingly positive and the reverse is true for a negative scan. A CV shows the peak currents and peak potentials for the anodic and cathodic reactions. The x-axis is potential (in volts) and the y-axis is the current (in amps). Also, a cyclic voltammogram demonstrates whether the redox reaction exhibits reversible or irreversible electrochemical behavior.

The important parameters for a cyclic voltammogram are E_{pa}, E_{pc}, i_{pa}, and i_{pc} which are the anodic and cathodic peak potentials and peak currents, respectively. (Figure 3)

Figure 3. Cyclic Voltammogram



An electrochemically reversible redox couple is one in which both species exchange electrons rapidly with the working electrode.

$$\Delta E = E_{pa} - E_{pc} \approx 0.058 / n \qquad (8)$$

Where n is the number of electrons transferred and E_{pa} and E_{pc} are the anodic and cathodic peak potentials in volts.

The peak potential is independent of scan rate but varies slightly with different switching potentials and cycle number. The formal reduction potential can be found midway between the two peak potentials:

$$E^{\circ\prime} = (E_{pa} + E_{pc}) / 2 \qquad (9)$$

The peak currents will increase with an increase in scan rate such that i_{pa} and i_{pc} are proportional to $\nu^{1/2}$. A plot of i_{pa} or i_{pc} versus $\nu^{1/2}$ should be linear and the magnitude of i_{pa} and i_{pc} should be similar [1, p 89].

A slow electron exchange at the working electrode will result in electrochemical irreversibility. The separation of peak potentials will be greater than 0.059 / n V and will be dependent on scan rate. Irreversible voltammograms are usually flatter and more spread out.

3. Modified Electrodes

A chemically modified electrode is one in which specific molecules are attached to the electrode surface in order to make it more reactive. By coating an electrode with a thin polymeric film, it can be used as a sensor. The reproducibility in the amount of polymer or the thickness of the film that is deposited is high. The polymer has great chemical stability such that degradation is not a problem. One way to synthesize a modified electrode is by applying a potential to a working electrode placed in a monomer solution. This will produce an electronically conductive polymer film on the electrode surface [1, p 408].

A chemically modified electrode has a higher selectivity toward the redox couple of interest. More interest in a class of neurotransmitters known as catecholamines has led to the development of polymeric thiophene-coated electrodes. These neurotransmitters are secreted in the brain at altered levels and have been associated with mental and behavioral disorders such as schizophrenia, attention deficient disorders, Alzheimer's disease, Parkinson's disease, eating disorders, epilepsy, amphetamine addiction, and cocaine addiction [4]. Ascorbic acid and catecholamines are oxidized at similar potentials which creates a problem in electrochemical analysis of the neurotransmitter. At physiological pH values, catecholamines are positively charged while ascorbic acid exists in its anionic form, ascorbate. By using a modified electrode with cation-exchange abilitites, selectivity to the oxidation of catecholamine is achieved [1, p 433]. Further, polymer films introduce additional active sites allowing electrochemical processes at their surfaces to be more pronounced than the electrochemical processes at unmodified surfaces. Polythiophenes, such as poly(3-methylthiophene), stand out among the numerous research projects done on electrochemically conducting polymers due to their processability, environmental stability, thermal stability, and ease of fabrication [5]. Using the modified electrode in combination with cyclic voltammetry, these neurotransmitters are easily investigated because no prior separation is required.

B. EDUCATION STRATEGIES

1. Concerns with Current Science Instruction

While the scientific method is the basis for which most science content is taught, there are limits to its effectiveness. The American Association for Advancement of Science (1993), National Research Council (1996 & 2000), and National Science Teachers Association (2003) have strongly rejected teaching science as a stepwise process [7]. Science instruction should be authentic and should follow more closely how scientists actually perform research [8]. Scientists develop questions and experiments, experience frustrating failures, expand research, collaborate with other scientists, and eventually find some of the answers they were originally seeking.

Science literacy has been defined by the National Science Education Standards (NSES) as certain key concepts in the natural sciences; how science relates to math, technology, and other human endeavors; an understanding of the nature of science as well as inquiry skills. Too often college students are not involved in their surrounding communities often stemming from the lack of interest in science and its relevance. Science literacy demands that students be able to apply their knowledge to the world around them. The four goals of NSES [9]:

1) Experience the richness and excitement of knowing about and understanding the natural world.
2) Use appropriate scientific processes and principles in making personal decisions.
3) Engage intelligently in public discourse and debate about matters of scientific and technological concerns.
4) Increase the students' economic productivity through the use of knowledge, understanding, and skills of the scientifically literate person in their careers.

Furthermore, the NSES states that inquiry skills are relevant at all levels of science education, emphasizing that science should be learned through practice, from K-12, through college, and into a professional research environment [10].

The average student is expected to learn and apply scientific concepts without any real foundation of why those concepts are important or relevant. The problems with a passive learning environment are well-documented. Students are neither actively involved in learning nor required to take responsibility for their learning. In a "traditional" classroom where lecture is the standard format for instruction, students are thinking while listening. For example, if an instructor is speaking approximately 150 words/min, students only hear about 50 words/min. In an average 50 minute class, students are inattentive for 40% of the time. In the first ten minutes of class, students retain only 70% of the information presented and retention falls to less than 20% in the last ten minutes of class [11]. After taking a test, almost 50% of what was memorized is lost and then over a period of weeks, the “forget curve” approaches 90%. However, information that was investigated via exploration or was really interesting to a student lasts much longer [12].

Furthermore, few basic science courses emphasize critical thinking (CT), logic (L), and problem-solving (PS) skills. Critical thinking displays mastery of intellectual skills and abilities. Logic is the relationship among propositions (supports, assumes, implies, contradicts, counts against, and is relevant to). Problem-solving is a process of reaching solutions. Practice in PS is essential in developing CT and a direct relationship exists between a student’s performance and logical thinking [13].

2. Objectivism and the Traditional Classroom

Most science instruction is based on the idea of objectivism. Objectivism is a theory which asserts that knowledge exists independently of the learner’s external and internal environment [12]. Knowledge is viewed as something that can be disclosed. An objectivist instructor has a traditional classroom where lecture is the primary means of getting students to learn. Furthermore, the students are rewarded only when their understanding of the subject material is basically the same as that of the instructor [14].

Traditional-style classes are teacher-oriented. The teacher has all the “knowledge” and students are required to learn what the teacher knows. This suggests that only a fixed body of knowledge exists and that students are expected to blindly accept and apply this knowledge. Because the teacher seeks to transfer thoughts and meanings to passive students, little room is left for student-initiated questions, independent thought, or interaction among students [15]. Also, lab activities do not encourage exploration or discussion of the concepts involved [16].

Most lab manuals used in undergraduate science courses only provide step-by-step instructions through an experiment but do not explain why the experiment is relevant to the student. Students become technicians, at most gaining knowledge of how to perform specific laboratory techniques, but do not experience what an actual scientist would. Thus, a student's sense of accomplishment occurs by completing all the experimental steps, not by having a thorough understanding of what was being investigated [17]. The results for many lab reports then are the "textbook answers" students commonly give to explain what might have happened in an ideal situation rather than analyzing their data for something more meaningful. No sense of personal achievement is gained in this setting, and the scientific process is reduced to steps performed to complete a lab report [18]. Thus, many students have no motivation to continue studying science.

Because people learn in different ways, it is important to adapt teaching methods to accommodate the diversity of students. Sensory learners depend on experiences taken in through their senses. Intuitive learners benefit from discussions of abstractions. Feeling learners tend to relate what they learn to their own personal and/or societal values. Thinking learners benefit most from a logical procession of organized and related concepts. No one person learns in just one way but usually some combination of the above [14].

Sensory-Thinking learners need a highly organized and quiet environment, memorize well, work best alone, and succeed on recall exams. This is the classic student for which the traditional-style classroom is designed. Sensory-Feeling learners work well in groups because they are highly interpersonal and learn through vocalization. Intuitive-Thinking learners need to see the whole picture of where specific knowledge fits and search for logic and patterns of understanding. Intuitive-Feeling learners are very creative and do well in cooperative learning situations, and are the most endangered students in a traditional style classroom. Thus it is necessary to explore new ways for science instruction that address the various ways students learn [14].

3. Constructivism

Contrary to the objectivist approach to teaching with traditional style lectures, constructivism is a "new" approach for instruction. As shown by the historical perspective, constructivism has actually been around for a long time [12]:

- Socrates, Plato and Aristotle show aspects of constructivist theory when speaking on formation of knowledge (470-320 B.C.).
- St. Augustine (354-430 A.D.) taught that in the search for truth people must depend upon sensory experience.
- John Locke (1632-1704) taught that no man's knowledge can go beyond his experience.
- Immanuel Kant (1724-1804) explained "the logical analysis of actions and objects leads to the growth of knowledge and the view that one's individual experiences generate new knowledge".

- Jean Piaget (1896-1980) considered father of constructivism; "Intelligence consists of two interrelated processes, organization and adaptation. People organize their thoughts so that they may make sense, separating the more important thoughts from the less important ones as well as connecting one idea to another. At the same time, people adapt their thinking to include new ideas, as new experiences provide additional information. This adaptation occurs in two ways, through assimilation and accommodation. In the former process, new information is simply added to the cognitive organization already there. In the latter, the intellectual organization has to change somewhat to adjust to the new idea."

Constructivism is a multi-faceted approach to the way people learn. It is a notion that humans construct meaning into their experiences and ideas that result from an investigation into understanding them. At times, it involves inventing new concepts or extending old concepts and recognizing new relationships between concepts. Two major principles are [12]:

1) Knowledge is not primarily received but is actively built up by the cognizing subject. Ideas and thoughts can not be communicated in the sense that meaning is 'packaged and sent' to another who unpacks the meaning.

2) The function of cognition is adaptive and serves the organization of experiential world, not the ontological reality. Truth is not found but constructed from viable explanations of experiences.

In science, a constructivist is one who acknowledges that students come into the science classroom with ideas about the natural world and are actively learning to make sense of everyday experiences. The constructed view of science is a "set of socially negotiated understandings of events and phenomena that comprise the experienced universe". Scientific knowledge is continually changing and evolving based on the new goals and problems of society, different individuals involved in the scientific community, and advances in technology [16, 19].

In a constructivist classroom, the teacher helps students incorporate new ideas into what they already know or think they know about the lesson being taught. Students are encouraged to ask questions that they may have to find the answers to themselves via discussion and exploration rather than just being told what the answer is. Teachers become facilitators and guide the learning process [16, 19]. Because the emphasis is taken off what the instructor knows, the importance of interactions among peers develops. When students have to explain ideas to their peers, perturbations of information can occur in both the presenter and the listeners which allows for further understanding and integration of knowledge when the discrepancies are resolved [16]. As shown later, the lab module that was developed encourages this new atmosphere of learning. The students are more responsible for their understanding of the experiment and not only have to collaborate with their peers but also find literature resources in order to complete the lab report.

4. Inquiry-Based Learning

Inquiry-based activities, founded in constructivist principles, teach science as a process rather than a defined method and increase student engagement and learning.

NSES states that "Students' understandings and abilities are grounded in the experiences of inquiry, and inquiry is the foundation for the development of understandings and abilities of other content standard." Students typically focus on scientific facts rather than the questions that led to the discovery of such facts [17].

Inquiry can exist is many different forms. Collaborative inquiry is when groups of students work together on an inquiry activity. Purposeful or guided inquiry occurs when a teacher provides students with a research question or when a specific skill or objective is being focused on in the inquiry. Open or free inquiry is a more pure, open-ended inquiry activity [8]. The inquiry lab module developed is both guided and collaborative. Inquiry involves but is not limited to the following:

- Observations
- Posing questions
- Examining books and other sources of information
- Using tools to gather, analyze, and interpret data
- Proposing predictions, answers, and explanations and communicating results
- Understanding use of assumptions and considering alternative explanations
- Developing critical thinking and problem-solving skills [10,20]

In an inquiry style class, the focus is put upon the student. The teacher becomes a facilitator and helps students to "come to know" facts instead of just presenting the facts. Students are not discouraged from making mistakes as long as they can explain the error and its implications [18]. Often the 5E model is used for inquiry:

1) Engage by initiating interest and excitement in the topic.

2) Explore by investigating and discussing different aspects of the topic in small, cooperative groups.
3) Explain by describing to others what their team has discovered.
4) Elaborate by expanding and investigating the topic further.
5) Evaluate by allowing students and teacher to assess what was learned.[16,21]

Preparations for inquiry-based instruction are more time-consuming but more fun and challenging than regular lectures, plus students are more accountable for learning and enjoy the class more [18].

For an inquiry-based experiment, writing about the lab in advance, having to do prior research or answering pre-test questions allows students to start thinking ahead of time about the experiment and what implications and connections it has to current course content or other knowledge [17]. A pre-test is designed to measure attitude toward instruction and subject matter content knowledge. Assessment after the lab can be done with a post-test, which is similar to pre-test content, and can measure what was learned and attitude towards the laboratory experience [22]. It has been shown that students perform better on assessments related to inquiry-based activities even if they were less successful on those activities compared to their traditional activities. Inquiry is most effective when the content follows closely along with what is being taught in lecture [23].

The role of college science teachers and use of inquiry in college science courses is currently being explored and implemented. Students need to be engaged in the process of scientific methods instead of just telling them about such methods. By encouraging students to ask and answer scientific questions, they can develop a deeper understanding of specific concepts being taught [24]. Overall, students learn more in class, spend more time in the library getting answers to questions including their own, improve test scores, learn how to address real-life problem situations, and perform better both in lab and in independent research work [13].

The implications of a need for change in the manner college science courses are being taught are overwhelmingly evident. Unfortunately, students are leaving science-related fields to non-science areas at a rate of 40% to 60% [25]. Students have varying motives for departing. Some experience difficulty with content, have pedagogical reasons, or cite personal experiences for their exodus. Students who leave science majors, switchers, and students who stay, non-switchers, share a common complaint of poor teaching and faculty pedagogy. A Constructivist Learning Environment Survey was given to students questioning their preferences and perceptions about being taught constructivistically. The results of the survey showed that the students in biology, chemistry, and physics courses were not being taught in the way that they preferred to be taught, i.e. in a constructivist environment [25].

C. PROJECT REEL

1. Goals and Objectives

The three overriding project goals for Project REEL (Research Experiences to Enhance Learning) are:

1) First, to transform the current 1st and 2nd year chemistry courses into a research-intensive program so students will pursue additional scientifically oriented

training, appreciate the scientific and ethical nature of research, and adopt the scientific method as a lifelong problem-solving technique.

2) To increase the retention and graduation rates in Science, Technology, Engineering, and Mathematics (STEM) fields.

3) To generate new knowledge in the chemical sciences through multi-site faculty-student collaborative research projects that pool their results in a common data base.

To achieve the three project goals, the objectives of the REEL project are to:

- Develop, implement, and evaluate two generations of Research/Lab Modules spanning three focus areas, biological/organic, environmental/analytical, and materials/inorganic, in 1st and 2nd year chemistry courses which are student-oriented, utilize discovery-based instruction, and provide for research-based experiences.
- Develop a flexible management structure that promotes communication and collaborative curricular programming for undergraduate research in chemistry.
- Build student learning communities in chemistry within and across institutions.
- Enhance the research capacity, infrastructure, and culture throughout Ohio by introducing Research/Lab Modules that employ accessible modern instrumentation.
- Facilitate access to site-bound instruments, promote intra-institutional

student collaborative projects/discussions, and link results from Research/Lab Modules across the state using Ohio's ultra high-speed electronic Third Frontier Network.

- Disseminate information via a web-based resource to raise student awareness of existing research opportunities in chemistry and related areas of science.
- Integrate the Research/Lab Modules into the curriculum at all the partner institutions.
- Increase graduation rates in STEM fields by raising student retention rates in 1st and 2nd year chemistry courses by at least 10% over current levels and monitor demographic and graduation trends.
- Increase student participation by at least 20% in traditional undergraduate research programs, regardless of their major.
- Increase the number of publications coauthored by undergraduates in refereed journals, poster sessions, and electronic journals.
- Perform a quantitative and qualitative longitudinal study that compares student outcomes in the current chemistry labs with those from the new research-intensive chemistry labs.
- Disseminate REEL's best practices and materials to relevant communities.

The central focus of the REEL Undergraduate Research Center has been the development and implementation of a series of Research/Lab Modules for use in the 1st and 2nd year chemistry courses in 15 Ohio institutions. Chemistry has never been, and will never be, an easy subject for many students. Most students in 1st and 2nd year courses are taking chemistry only because it is required in their curriculum. Furthermore, students sometimes lose enthusiasm for chemistry and science because they fail to see the links to real-life challenges and opportunities. Thus, the primary challenge in these early courses has been to help prepare students for the as-yet-unknown chemistry-related tasks they will face in their future careers and for their role as responsible citizens in an increasingly complex technological world.

Chemistry is, by its nature, an experimental science. An interesting paradox is that the cognitive skills that are neglected in most introductory level chemistry laboratories are exactly those needed for success in chemical research. Inherently, research has involved a more independent and open-ended type of thinking which permits the frustrations of failed experiments, the challenge of learning from failures, and occasionally the exhilaration of successful experiments. This project has involved the expertise of colleagues on 15 campuses to collectively develop Research/Lab Modules that will introduce research topics and concepts into the chemistry curriculum for ALL students during their 1st and 2nd year chemistry courses. The overarching goal of this approach was not to pick out a select group of students and involve them in traditional research, but rather to transform the way chemistry is taught in these courses to expose all students to the excitement, relevance, and concepts of cutting edge chemical research.

The Research/Lab Modules have enabled faculty to introduce a broad range of specific research projects. Furthermore, this approach will show students the relevance of science and technology to their world, by incorporating real-life collaborative research projects as a means of increasing student interest in the sciences and improving their readiness to apply general concepts to practical systems. This method has been coupled with a conscious effort to make these students aware of other research opportunities in order to significantly enhance the flow of undergraduates into existing research groups and programs in all areas of science.

Only by becoming involved in an actual research project can a student gain the working knowledge needed to master that area and to appreciate achievements in other scientific areas. Some institutions introduce a limited number of students to research opportunities from the 1st and 2nd year chemistry courses, sometimes using Research/Lab modules. The REEL tactic, on the other hand, has been to introduce smaller amounts of research to all students as they move through the 1st and 2nd year courses. The model appears to offer an effective use of resources to impact the largest number of students. At the lead institution alone (The Ohio State University), approximately 3000 students have been introduced to research in the first quarter course each year by the completion of the project.

The approach assures that the full diversity of students normally enrolled in these courses will benefit from the changes, and that even a student who takes only one course in chemistry will have at least a modest introduction to research. The longer students stay in the chemistry curriculum, the more intense will be their experiences in research, with an expectation that more students will then be trained for and motivated to participate in traditional undergraduate research programs. Additionally, the new and innovative Research/Lab modules have been incorporated by individual institutions into their existing course structure in the manner and order which best fits their overall curriculum, thereby ensuring the sustainability of the REEL project.

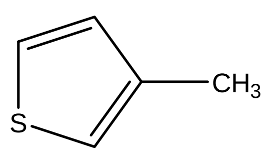
2. Project Impact

All 15 institutions involved in REEL have some form of one-on-one student-faculty research mentorship for their chemistry majors. The idea proposed in the REEL project was to introduce research as a learning tool for all 1st and 2nd year chemistry classes. Currently, about 47% of Ohioans have completed some college compared to the national average of 52%; but only 21% of Ohioans receive baccalaureate or higher degrees, putting Ohio 39th in the nation. Under-represented minorities account for 13.6% of the total Ohio population. Currently only 6.2 % of bachelor degrees in STEM fields are awarded to minorities at the major public Ohio universities. The average number of STEM graduates from each Ohio institution is 1,296 per year over the last three years, and this represents 16.5% of the total number of undergraduate degrees awarded. Only about 40-50% of STEM students in Ohio become involved in undergraduate research. The REEL project should have a profound impact on the learning process of about 14,000 undergraduates per year at the partner institutions and result in significantly larger numbers of students being interested in pursuing degrees in STEM fields [26].

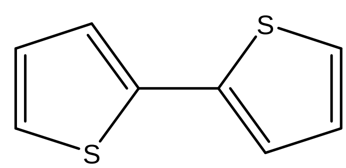
3. Aims of the Present Work

As mentioned previously, using conductive polymer modified electrodes to detect neurotransmitters with cyclic voltammetry has been explored. Combining this experimental work with the need for a novel inquiry-based lab brought about my participation in Project REEL. In the following paragraphs, I will explain in detail how the lab module was developed. For this research project, the monomers used for electropolymerization in creation of the modified electrode are 3-methylthiophene and 2,2’-bithiophene. The polymer film synthesis is initiated by oxidation of the monomer to form free radical cations which then undergo dimerization followed by the loss of protons to yield a neutral dimer. The dimer is oxidized and follows the same mechanistic pathway to elongate the chain. As the polymers are formed, doping occurs by loss of electrons creating positively charged sites along the polymer [6]. See Figure 4.

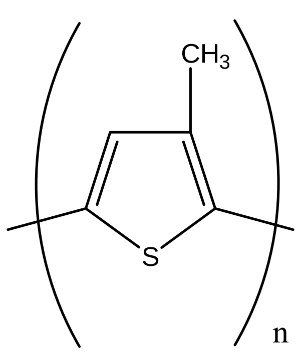
Figure 4. Structures of 3-Methylthiophene, 2,2’-Bithiophene, Poly(3-methylthiophene), and Poly(2,2’-bithiophene)



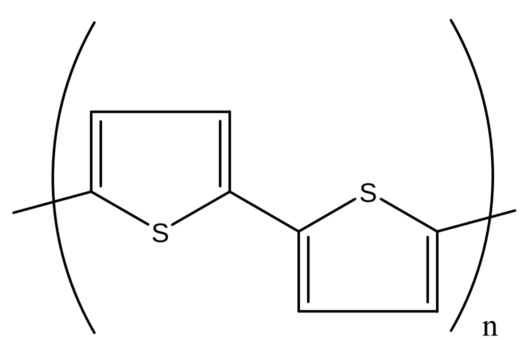
3-Methylthiophene



2,2’-Bithiophene



Poly(3-methylthiophene)



Poly(2,2’-bithiophene)

I learned how to create the poly(3-methylthiophene) (P-3MT) modified electrode and use it for simultaneous detection of catechol and ascorbic acid. 2,2'-Bithiophene and 3-methylthiophene have similar structural characteristics which led to trying to create a poly(2,2'-bithiophene) modified electrode. Furthermore, 2,2'-bithiophene is a solid at room temperature and is less hazardous to handle. The flashpoint of 3-methylthiophene is -1°C while the flashpoint of 2,2'-bithiophene is 110°C. I created the poly(2,2'-bithiophene) sensor and published a paper with this work [27]. Becoming involved with project REEL, I had the opportunity to take my research and create a lab for first year chemistry students to perform. The motivations for developing the lab module were two-fold:

1) As a teaching assistant (and as someone who would like to teach chemistry), I have had first hand experience with the lack of understanding associated with the step-by-step experiments freshman students perform. Not only do they not see the real world applications of these labs but they seem to be very uninterested in the content.

2) I was excited to be studying something as simple as oxidation and reduction reactions, but applying and seeing its importance in a whole new way. My hope was that the students would become as excited and want to pursue further studies in chemistry or at the least, not hate it as much.

Therefore, the goal of this lab module was to provide an inquiry-based experiment involving oxidation and reduction reactions in a 1st year Chemistry course, teaching both real-world problem solving skills and critical thinking. Many 1st year chemistry students perform labs that do not pertain to their fields of study, such as medicine or engineering. Also, undergraduate students are not exposed to the type of instrumentation set forth by this lab module. The experiment was created to excite students in their chemistry studies and hopefully encourage them to stay in STEM fields.

This lab module has created a challenging, guided and collaborative inquiry experiment for the students to complete. It introduces students to using electrochemical techniques; investigation of the viability of the polymeric electrode; and with creation of the sensor, addresses the real-world incorporation of chemistry, medicine, and engineering. For an inquiry-based lab, I developed pre and post-test questions to assess the content gain as well as a project survey to get the students' feedback for the lab module.

The experiment requires the synthesis of a poly(3-methylthiophene) or poly(2,2'-bithiophene) modified electrode. The students gain problem-solving skills by having to compare the platinum and glassy carbon as the working electrode to see which gives better results as well as comparison to the bare electrodes. Cyclic voltammetry is used to simultaneously study the redox reactions of catechol and ascorbic acid. The students have to utilize their cyclic voltammograms and collaborate with each other to answer the lab report questions. Furthermore, in order to successfully answer the lab report questions, the students must obtain and review the references cited in the lab module, which promotes science literacy.

II. EXPERIMENTAL

The students performing this lab module are mostly chemistry, biology and pre-med majors. A lab recitation is given by a teaching assistant to explain the experimental procedure, basic electrochemistry terminology, and to provide information regarding Project REEL. This lab is performed at the end of the quarter after electrochemistry has been taught during the lecture portion of the course. The students worked in groups of four to six and were assigned to one of the three instruments.

I created the experiment and the treatment of data/ inquiry which is given to the students to perform and is seen below as the lab module. Prior to coming to the laboratory to complete the experiment, students are required to read the article "Electrochemistry and Detection of Catechol at a Conducting Poly(3-methylthiophene) Electrode in the Presence of a Common Interferent, Ascorbic Acid", which is given as an additional handout.

I constructed the pre/post-test questions as a means to assess the students' content gain. Included in the test are basic questions concerning drawing chemical structures, oxidation and reduction, and an electrochemical cell, as well as more advanced questions regarding electrodes, polymers, and cyclic voltammetry. The pre-test is given during the lecture class before any electrochemistry is taught and the students are allowed 20 minutes to complete the test. The post-test is given during the lecture class one week after the lab has been completed and the time allotted to take the post-test is the same as the pre-test.

Finally, I developed a post-project survey to assess how the students felt about their experiences in project REEL.

A. Lab Module

Detection of Catechol in the Presence of Ascorbic Acid: Development of an Electrochemical Sensor, Chemistry 123 Lab

<u>Purpose:</u>

The purpose of this lab is for students to develop more advanced research skills in electrochemistry, analytical chemistry, and biological and neurological sensors. The modified electrodes, or neurological sensors, created will aid in the detection of catechol in the presence of ascorbic acid. Catechol is of interest to neuroscientists as it is secreted in the brain, and altered levels of this compound have been associated with mental and behavioral disorders such as schizophrenia, attention deficient disorder, Alzheimer's disease, Parkinson's disease, eating disorders, epilepsy, and amphetamine and cocaine addiction. Because catechol undergoes oxidation within the usable potential range for aqueous electrochemistry, it can be detected by using a modified electrode sensor. Cyclic voltammetry is an electrochemical method that has become very popular in analyzing redox reactions (oxidation and reduction). The goal of this research lab is to develop an electrochemical sensor with modified poly(3-methylthiophene) (P-3MT) and poly(2,2'-bithiophene) (P-BTP) platinum or glassy carbon electrode to detect catechol by cyclic voltammetry in the presence of ascorbic acid, a common interferent. Students will determine if the developed sensor electrode has successfully detected catechol without need for prior separation from the ascorbic acid.

References:

1. J.J. Van Benschoten, J.Y. Lewis, W.R. Heineman, D.A. Roston, and P.T. Kissinger, J. Chem. Ed., 60, 772 (1983).
2. W.R. Heineman and P.T. Kissinger, "Laboratory Techniques in Electroanalytical Chemistry," Marcel Dekker, New York, 1984.
3. D.T. Sawyer, W.R. Heineman, and J.M. Beebe, "Chemistry Experiments for Instrumental Analysis," John Wiley & Sons, New York, 1984.
4. H.B. Mark, Jr., N. Atta, Y.L. Ma, K.L. Petticrew, H. Zimmer, Y. Shi, S.K. Lunsford, J.F. Rubinson, and A. Galal, Bioelectrochem. Biolenerg. 39, 229 (1995).

<u>Apparatus/Equipment:</u>

Instrument for cyclic voltammetry such as Bioanalytical Systems, Epsilon model, platinum working electrode, glassy working electrode, platinum auxiliary electrode, Ag/AgCl/3M NaCl reference electrode, electrochemical cell, nylon cloth with 2 micrometer alumina polish, nylon cloth with 0.05 micrometer alumina polish, volumetric flasks (10 mL, 50 mL, 100 mL, 1000 mL), disposable pipets and pipet bulbs, analytical balances.

Chemicals:

Catechol, tetrabutylammonium tetrafluoroborate (TBATFB), acetonitrile (HPLC grade), ascorbic acid, sulfuric acid (ACS reagent), 3-methylthiophene, 2,2'-bithiophene, acetone.

Safety Cautions:

Wear goggles and safety apparel throughout the lab experiment to prevent any harm to skin and eyes. Sulfuric acid is corrosive and causes severe burns. It is a strong dehydrating agent. Do not breathe vapors and do not get on skin, in eyes, or on clothing. 3-Methylthiophene is highly flammable and harmful by inhalation and if swallowed. Acetonitrile is flammable, toxic and harmful by inhalation, contact with skin, and if swallowed. 2,2'-Bithiophene is harmful if in contact with the skin or eyes. This material can produce cyanide-like effects and targets areas of the body such as the central nervous system and liver. Tetrabutylammonium tetrafluoroborate (TBATFB) is harmful by inhalation, contact with skin, and if swallowed. TBATFB is also irritating to eyes and respiratory system. Catechol is harmful if in contact with skin and if swallowed. It reacts readily with light. Catechol targets the liver and central nervous system. Acetone is flammable and irritating to the eyes and targets the liver, kidneys, and nerves.

Procedure:

Prepare the working electrode (carbon or platinum) by polishing with a nylon cloth using a 2 micrometer diamond paste. Then polish working electrode with a nylon cloth using a 0.05 micrometer alumina polish. Care must be taken not to scratch or contaminate the polished working electrode surfaces before the polymerization process.

Prepare a 0.05 M 3-methylthiophene solution and dilute with electrolyte solution (0.1 M tetrabutylammonium tetrafluoroborate (TBATFB) diluted with acetonitrile) or a 0.05 M 2,2'-bithiophene solid and dilute with electrolyte solution (0.1 M tetrabutylammonium tetrafluoroborate (TBATFB) diluted with acetonitrile).

Students should read the Epsilon handout on how to run the cyclic voltammtery instrument before proceeding. *Check with facilitator/teaching assistant to make sure the instrumentation and solutions are correctly prepared before running any cyclic voltammograms of the working electrodes.* Run a cyclic voltammogram at a scan rate of 100 mV/s with a scan range of 2500 mV to 0.0 mV for a working electrode in the prepared 0.05 M 3-methylthiophene solution or the prepared 0.05 M 2,2'-bithiophene solution. Data from the cyclic voltammogram should assist in determining what potential is required and what length of time is needed to electropolymerize/modify the electrode to create the poly(3-methylthiophene) electrode or the poly(2,2'-bithiophene) electrode. *Check with facilitator/teaching assistant to ensure that the correct constant potential and time has been determined to create the polymer electrode surface.*

Once the modified working electrode sensor has been created under the constant potential conditions from the above procedure, prepare 0.005 M catechol in 0.1 M sulfuric acid. Set up the three-electrode compartment cell with the newly made 0.005 M catechol solution. Run a cyclic voltammogram at a scan rate of 100 mV/s with a scan range of 800 mV to 0.0 mV using the modified P-3MT or P-BTP electrode. *Check with facilitator/teaching assistant to see if results are reproducible.* Three scans should be run with the modified working electrode and the cyclic voltammograms should be reproducible.

Prepare a new polymeric modified working electrode as described previously. Prepare 0.005 M ascorbic acid and dilute with 0.1 M sulfuric acid. Set up the electrochemical cell with fresh 0.005 M ascorbic acid solution, newly modified electrode, and run a cyclic voltammogram with the above stated parameters. Run three trials to see if the results are reproducible. Can the P-3MT or P-BTP electrode sensor be utilized to detect catechol in the presence of ascorbic acid?

Prepare another modified polymer electrode. Prepare a solution of 0.005 M catechol/0.005 M ascorbic acid diluted with 0.1 M sulfuric acid. Set up the electrochemical cell with 0.005 M catechol/0.005 M ascorbic acid solution and run a cyclic voltammogram under the same conditions. Perform three trials and record the results of detection of catechol in the presence of ascorbic acid. *Check with facilitator/teaching assistant to see if results are reproducible.*

<u>Treatment of Data/Inquiry:</u>

Read suggested references and refer to literature for assistance with answering the following questions:

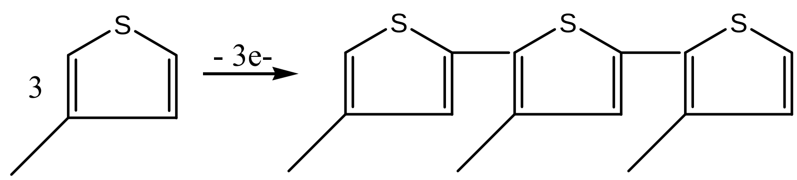
1) Write the electrochemical polymerization mechanism for the poly(3-methylthiophene).
2) Write the electrode reaction that is occurring for each peak of the cyclic voltammogram of catechol and of ascorbic acid. Label oxidation and reduction peaks.
3) Which cyclic voltammograms were reversible, irreversible, or quasi-reversible from your results?

4) Which modified electrode gave the best results—platinum electrode or glassy carbon electrode? (This question can only be answered with collaboration from all the groups as different groups will use the platinum electrode or glassy carbon electrode.)
5) From the literature references, was it necessary to modify the electrode in order to detect catechol in the catechol/ascorbic acid solution?
6) From the literature references, determine the peak separation of the modified electrode sensor response to catechol and compare to the bare electrode response to catechol. Which gave the best results? Explain.

B. Lab Module Assessments

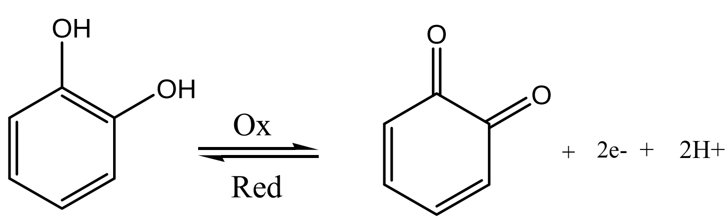
1. Answers to Treatment of Data/Inquiry

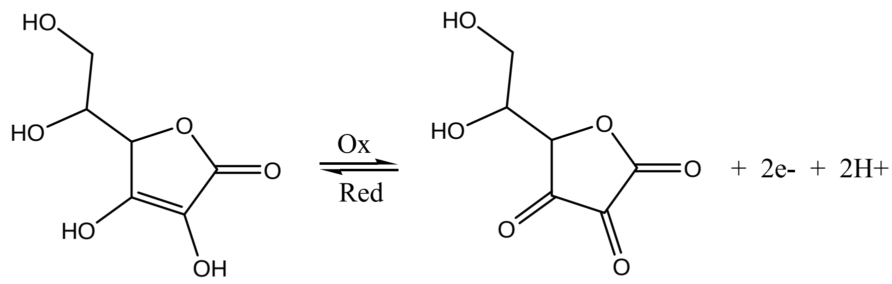
1) Write the electrochemical polymerization mechanism for the poly(3-methylthiophene).



The monomers oxidize to form free radical cations which then react, and the loss of protons occurs to form the neutral dimer. The dimer forms a free radical cation which reacts with another oxidized monomer and protons are lost to form the polymer. Oxidation of the final polymer results in its ability to be a conducting polymer.

2) Write the electrode reaction that is occurring for each peak of the cyclic voltammogram of catechol and of ascorbic acid. Label oxidation and reduction peaks.





3) Which cyclic voltammograms were reversible, irreversible, or quasi-reversible from your results?

    Ascorbic acid is irreversible and catechol is reversible.

4) Which modified electrode gave the best results—platinum electrode or glassy carbon electrode? (This question can only be answered with collaboration from all the groups as different groups will use the platinum electrode or glassy carbon electrode.)

    The platinum electrode worked better as the modified electrode because the cyclic voltammograms show increased resolution of the oxidation and reduction peaks for catechol and the oxidation peak for ascorbic acid.

5) From the literature references, was it necessary to modify the electrode in order to detect catechol in the catechol/ascorbic acid solution?

    Catechol can be detected on a bare platinum electrode but the oxidation and reduction peaks are very small. When trying to detect catechol in the presence of ascorbic acid on a bare platinum electrode, the oxidation peaks are not resolved and the reduction peak for catechol is not present. Using one of the modified polymer electrodes, the detection of catechol and ascorbic acid can be done at the same time.

6) From the literature references, determine the peak separation of the modified electrode sensor response to catechol and compare to the bare electrode response to catechol. Which gave the best results? Explain.

   The peak separation for the CV resulting from the modified electrode should be very small (<100 mV) while the bare platinum electrode has a CV with large separation between peaks (>300 mV). The modified polymer electrode detects the catechol better as the oxidation and reduction peaks are much more defined.

2. Pre/Post-Test

1) What is an electrochemical cell?

2) What is a working electrode, reference electrode, and auxiliary electrode?

3) Draw the Lewis structures for Catechol, $C_6H_6O_2$, and Ascorbic Acid, $C_6H_8O_6$.

4) Define oxidation and reduction in terms of electron transfer and charge.

5) What is cyclic voltammetry?

6) What is a polymer? Is 3-methylthiophene a polymer?

7) Identify the species that are reduced and oxidized in the following reaction and write a balanced equation: MnO_4^- (aq) + $C_2O_4^{2-}$ (aq) → Mn^{2+} (aq) + CO_2 (g)

8) If the formula for catechol is $C_6H_4(OH)_2$, write the oxidation and reduction reactions.

3. Answers for the Pre/Post-Test

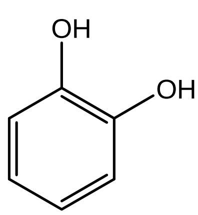
1) What is an electrochemical cell?

   Two electrodes separated by at least one electrolyte phase with a measurable potential difference between them. Cells can be electrolytic or galvanic.

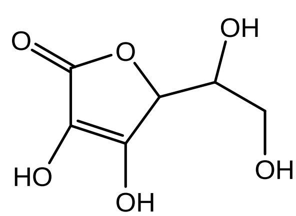
2) What is a working electrode, reference electrode, and auxiliary electrode?

   A working electrode is the electrode of interest where the reaction takes place. The reference electrode is an ideal nonpolarizable electrode of known potential. An auxiliary electrode is an electrode that does not affect the working electrode and is usually separated from the reference and working electrodes.

3) Draw the Lewis structures for Catechol, $C_6H_6O_2$, and Ascorbic Acid, $C_6H_8O_6$.



Catechol



Ascorbic Acid

4) Define oxidation and reduction in terms of electron transfer and charge.

   Oxidation is loss of electrons and increase in positive charge. Reduction is a gain of electrons and an increase in negative charge.

5) What is cyclic voltammetry?

Cyclic voltammetry occurs with the cycling of the potential of an electrode which is in an unstirred solution and the resulting current is measured. The result is a cyclic voltammogram which has oxidation and reduction peaks directly related to the applied potential and measured current.

6) What is a polymer? Is 3-methylthiophene a polymer?

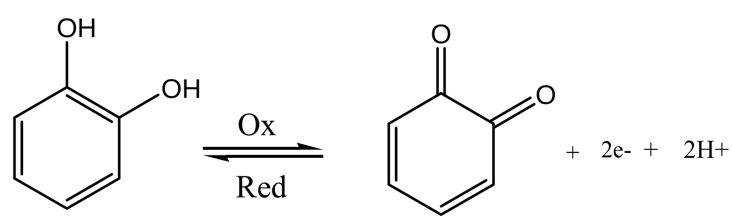
A polymer is a large molecule with a large molecular weight that is composed of repeating units of a small molecule with low molecular weight called a monomer. No, 3-methylthiophene is not a polymer it is a monomer.

7) Identify the species that are reduced and oxidized in the following reaction and write a balanced equation: MnO_4^- (aq) + $C_2O_4^{2-}$ (aq) → Mn^{2+} (aq) + CO_2 (g)

MnO_4^- is reduced and $C_2O_4^{2-}$ is oxidized.

16 H^+ (aq) + $2MnO_4^-$ (aq) + $5C_2O_4^{2-}$ (aq) → $2Mn^{2+}$ (aq) + $10CO_2$ (g) + 8 H_20 (l)

8) If the formula for catechol is $C_6H_4(OH)_2$, write the oxidation and reduction reactions.



4. Post Project Survey

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

2. What did you like the *least* about your experience with this REEL project?

3. What would you change or improve in the next implementation of this REEL project?

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

III. RESULTS AND DISCUSSION

The results of the lab module show the data obtained from the electrochemical detection of catechol and ascorbic acid on the poly(2,2'-bithiophene) modified electrode. The P-BTP electrode was a new sensor that had not been used in the detection of catecholamines prior to my research. All of the cyclic voltammograms are ones that I produced during my research and exemplary of what the students did in the lab module. Furthermore, content gain is assessed with a pre/post-test analysis and responses to the effectiveness of the inquiry lab module are addressed.

A. Lab Module

The data in Table 1 display how the applied potentials varied for the synthesis of the P-BTP electrode surface and how this parameter affects the cyclic voltammogram peak separation values [28-31]. The P-BTP formed under optimized conditions (+1.8 V) allowed for improved electrochemical reversibility, selectivity, and reproducibility for the detection of catechol as illustrated in Table 1. The peak separation decreases as the electropolymerization potentials increase in value for the modified P-BTP platinum electrode. The P-BTP electrode at +1.8 V synthesis indicates that the reversibility of catechol oxidation is significantly improved with $\Delta E = 123$ mV compared with the bare platinum electrode with a $\Delta E = 221$ mV [32].

Figure 5 shows cyclic voltammograms of catechol indicating reversibility while Figure 6 illustrates cyclic voltammograms of ascorbic acid indicating irreversibility. Reversibility is shown by the oxidation and reduction peaks of the CV for catechol. Irreversibility is indicated by only the oxidation peak existing for ascorbic acid.

Table 2 illustrates that catechol can be detected in the presence of ascorbic acid, a common interferent. Optimum sensor results are obtained for the synthesis of the modified P-BTP electrode at +1.8 V.

The cyclic voltammograms in Figure 7 illustrate the selectivity principle in the electrochemical detection of catechol in the presence of ascorbic acid. Ascorbic acid shows irreversible behavior in 0.1 M sulfuric while catechol shows reversible behavior. The cyclic voltammograms of the mixture of catechol and ascorbic acid in equimolar concentrations is shown, proving the oxidation peaks of catechol and ascorbic acid are being resolved and the reduction peak for catechol is detected. However, cyclic voltammograms at the bare platinum electrode have oxidation peaks of catechol and ascorbic acid that are not resolved, and the reduction peak of the oxidized catechol is not detectable [32].

Further analysis was carried out to determine which modified working electrode, platinum or glassy carbon, gave the optimum electrocatalytic response to catechol in the presence of ascorbic acid. Referring to Figure 7 and comparing it to Figure 8, it can be seen that the P-BTP/Pt electrode yields better results than the P-BTP/GC electrode. The peak potentials for the modified platinum electrode show enhanced resolution.

Table 1. Peak Potentials of Catechol and Ascorbic Acid on a P-BTP/Pt Electrode

Catechol	Ep_a (mV)	Ep_c (mV)	Δ E (mV)
+1.5 V	601	414	187
+1.6 V	590	427	163
+1.7 V	579	448	131
+1.8 V	573	450	123
Ascorbic Acid			
+1.5 V	470	--------	-------
+1.6 V	437	--------	-------
+1.7 V	407	--------	-------
+1.8 V	402	--------	-------

Table 2. Peak Potentials of an Equimolar Mixture of Catechol and Ascorbic Acid on a P-BTP/Pt Electrode

Potential	Ep_a (mV) (Ascorbic Acid)	Ep_a (mV) (Catechol)	Ep_c (mV) (Catechol)	ΔE (mV)
+1.5 V	450	582	458	124
+1.6 V	421	577	458	116
+1.7 V	402	575	467	108
+1.8 V	402	575	467	108

Figure 5. Cyclic Voltammograms of 0.005M Catechol Solution on a P-BTP/Pt Electrode

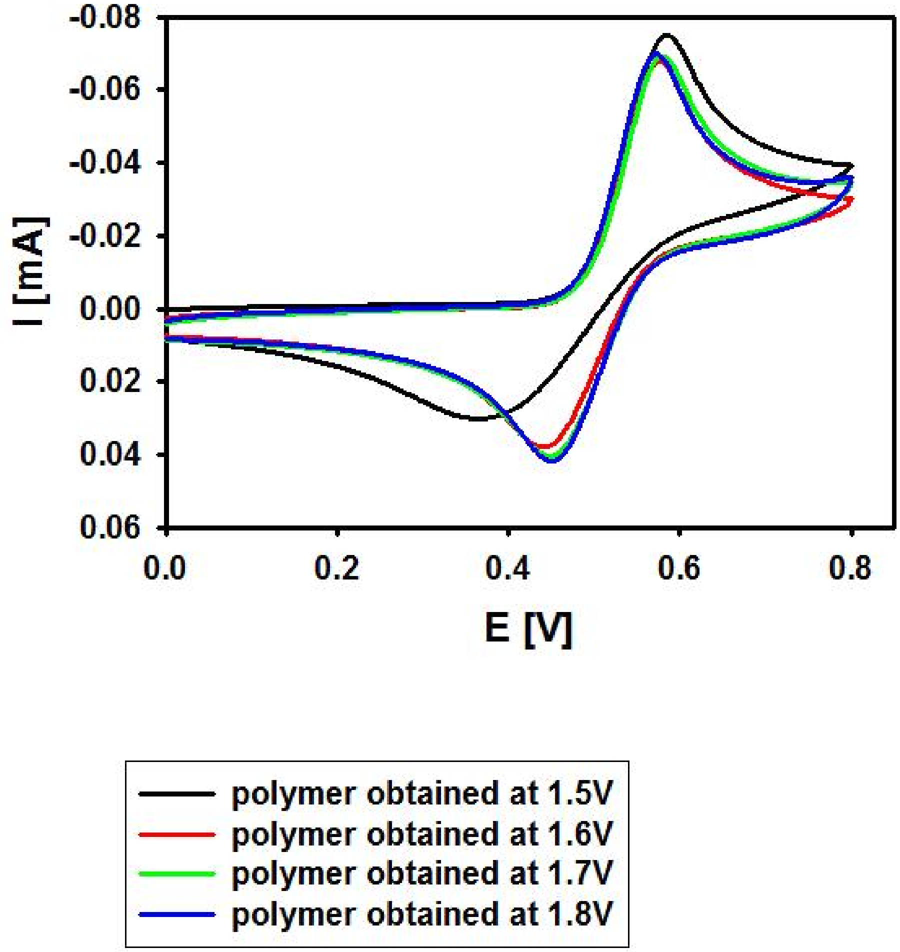


Figure 6. Cyclic Voltammograms of 0.005M Ascorbic Acid Solution on a P-BTP/Pt Electrode

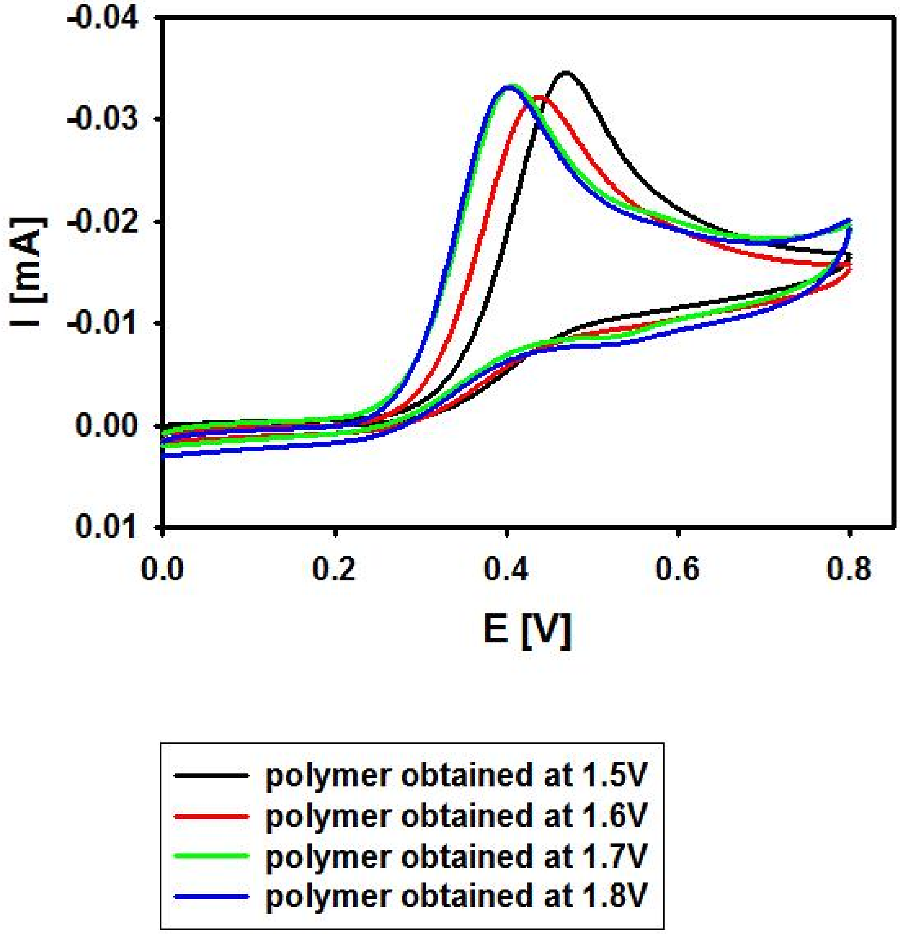


Figure 7. Cyclic Voltammograms of 0.005 M Catechol and 0.005M Ascorbic Acid Solution on a P-BTP/Pt Electrode.

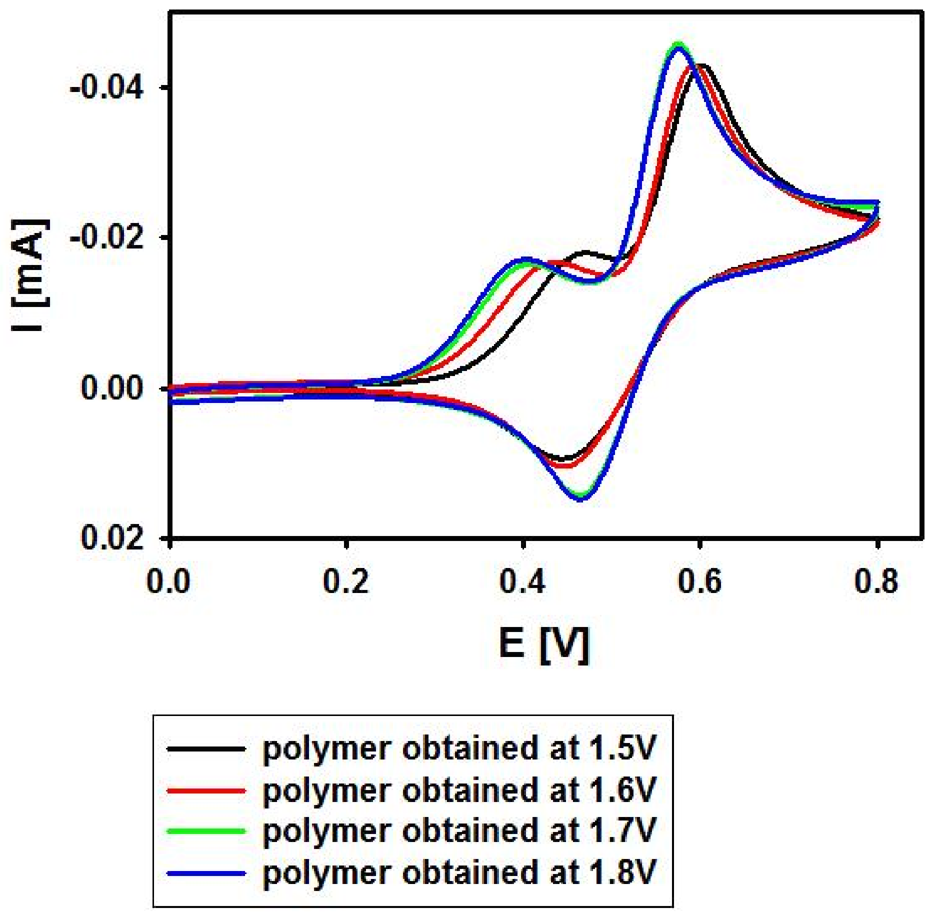
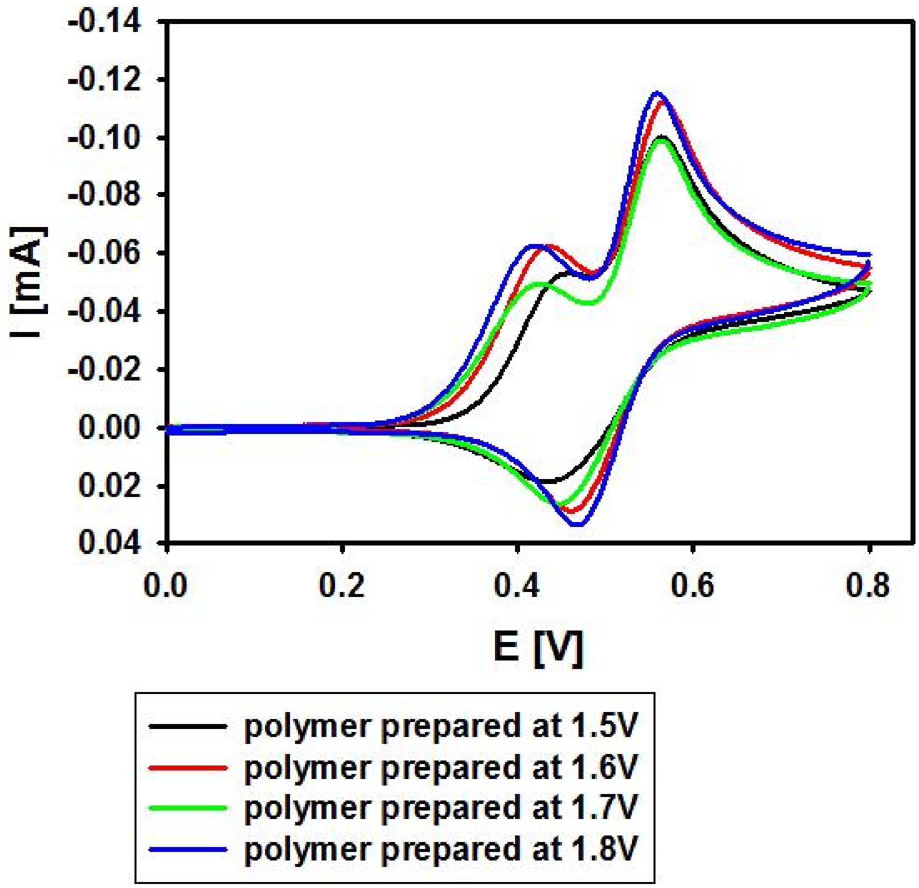


Figure 8. Cyclic Voltammograms of 0.005M Catechol and 0.005M Ascorbic Acid on a P-BTP/GC Electrode



B. Pre/Post-Test Analysis

Table 3. Pre/Post-Test Scores

Student	Pre-Test (%)	Post-Test (%)
A	31.250	75.000
B	25.000	68.750
C	6.250	59.375
D	37.500	96.875
E	15.625	53.125
F	3.125	68.750
G	18.750	62.500
H	12.500	68.750
I	18.750	75.000
J	21.875	46.875
K	28.125	62.500
L	6.250	68.750
M	25.00	96.875
N	18.750	93.750
O	6.250	90.625
P	9.375	31.250
Q	9.375	78.125
R	18.750	84.375
S	25.000	53.125
T	6.250	87.500
U	12.500	87.500
V	12.500	68.750
W	0.000	68.750
X	12.500	87.500
Y	18.750	93.750
Z	6.250	68.750
A1	12.500	56.250
B1	0.000	75.000
C1	0.000	93.750
D1	18.750	100.000
E1	25.000	93.750
F1	0.000	56.250
G1	18.750	93.750
H1	25.000	93.750
I1	6.250	68.750
J1	12.500	87.500

Table 3. Pre/Post-Test Scores (Continued)

Student	Pre-Test (%)	Post-Test (%)
K1	6.250	81.250
L1	12.500	81.250
M1	12.500	68.750
N1	3.125	62.500
O1	15.625	62.500
P1	21.875	78.125
Q1	25.000	81.250
R1	21.875	78.125
S1	12.500	68.750

The students had to take the pre-test prior to completing the experiment to see what their content knowledge was of electrochemistry and polymers. The post-test was given after the lab was finished to assess the content gain. Pre/Post-test analysis is part of an inquiry-based experiment. Table 3 shows the results of the graded tests. After calculating the average pre-test and average post-test scores, content gain is determined by using the following formula:

- Normalized Gain= (Post-Test - Pre-Test) / (100 – Pre-Test)

R.R. Hake states that a normalized gain greater than 0.7 means a high content gain, 0.3-0.7 is a medium gain in content and less than 0.3 is an extremely low content gain [33]. The low gain is seen with a typical "cook book" lab where the inquiry-based module illustrates a high gain. The lab module results for the pre/post-test analysis show a normalized content gain of 0.71, indicating a high gain. While only a small population of students has participated so far, the results are very promising. Performance on the pre/post-test is somewhat dependent on the attitude and accessibility of the facilitator responsible for teaching the lab module. The analysis shows that the students were fairly successful in understanding the inquiry lab module. However, in order to more fully assess these results, further investigation should be made by converting this lab module to a traditional step-by-step experiment and have those students performing the traditional lab take the same pre/post-tests. A comparison could then be made between the content gain resulting from the inquiry-based lab module and the content gain resulting from the traditional lab.

C. Project Survey Responses

The students were given a survey, as shown on page 44, to provide feedback of their experiences with their participation in the REEL Project. The student responses can be seen in Appendix A. Students liked the real-world application of the lab, that it was challenging, and learning both electrochemistry and new instrumentation. Some of the student's general complaints were that they were not given enough time to complete the experiment, the space was cramped, the instruments were limited for the number of students present and the facilitator was not able to assist as much as was necessary. The most common complaint though was that the lab was too difficult and very confusing. The suggested changes were to have a longer time period to do the lab, to work in smaller groups, and to have better explanations for the experiment. Finally, the students may have struggled a bit and encountered difficulties with the material, but most of them were more encouraged and excited to pursue undergraduate research.

Most of the problems encountered during the lab were difficulties with students preparing solutions. Some students lacked basic understanding in how to calculate molarity and how that translated to the amount of monomer needed to create those solutions as well as in performing dilutions. To circumvent this issue, the TA would prepare the solutions. Furthermore, if the electrodes were not cleaned properly or the electrochemical cell was not rinsed efficiently between scans, poor results on the cyclic voltammograms were obtained. Having to repeat scans was a major frustration for the students.

IV. CONCLUSION

Inquiry-based learning gained momentum in the 1970's but this approach has not yet been widely accepted by college/university professors. Because inquiry has become more central in precollege science classes, college faculty members are realizing the need to change from traditional teaching methods. Most science is taught as a summary of facts that need to be memorized in order to succeed on a test, while real comprehension is not emphasized nor rewarded. Inquiry-based learning occurs when students seek information by asking questions and constructing new knowledge. When students are involved in a discovery process, the result is better understanding of the material being discovered and development of CT (critical thinking) and PS (problem-solving) skills). CT occurs when a student is able to determine the reason for change in a variable and how it affects change in other variables. CT also allows for integration of information from different sources to explain events and predict outcomes. Working in small groups, students can collaboratively develop CT and PS skills by negotiating ideas and realizing that no finite set of answers exists to the given questions. This forum aids students in class and throughout life [14, 20].

There is a definite need to move away from teaching 'Science as a noun', which stresses endless volumes of knowledge and lists of procedures and processes about science. Thus, science instruction focuses generally on covering content while exposing students to a large quantity of facts. The two consequences of 'science as a noun' are [34]:

1. Students develop false beliefs about the nature of science believing that science redescribes an event or phenomenon; that an authority figure warrants what can be considered scientific knowledge; that scientific knowledge is only acquired through an empirical process.
2. Students who are taught science this way are prone to either develop or maintain strong misconceptions about science-related concepts.

Therefore, the goal of science education should be to help students develop an understanding of the nature of science by participation in authentic real-life contexts.

The students in Project REEL have participated in an inquiry-based lab module, which reflects a real-world application. They have come to see why it is important to understand this type of chemistry because it has relevance outside the classroom. The lab module has put a new and exciting twist on studying oxidation and reduction reactions as the students study neurotransmitters and electrochemical techniques. Some of the students who participated in the REEL project have gone on to pursue undergraduate research, thus, one of the goals to retain students in STEM has been met. Furthermore, this lab module has been implemented at The Ohio State University and work is being done to bring it to Southern State Community College. A more quantitative study in the effectiveness of the lab modules is being done through Project REEL, however the results will not be disclosed for another two years.

The feedback from the project survey that has been provided though does indicate that the information presented in the lab is a bit too complex for freshman students to understand. The instrumentation utilized for the lab was somewhat complicated, yet any new instrument a chemistry student would encounter for the first time would seem a little daunting. However, one of the advantages to this experiment is that it takes about a minute to create the modified electrode and even less time to produce a cyclic voltammogram. So if the solutions are made properly and the electrodes and electrochemical cell are cleaned thoroughly, the time it takes to complete the lab isn't very long. Unfortunately, if the students try to rush through preparing solutions or cleaning the working electrode, the experiment can be quite time-consuming.

As seen previously, more instruments would need to be added to make the lab proceed more smoothly as well as decrease the size of the groups. I think that this would help to eliminate some of the organizational issues brought up by the students. Furthermore, by having the students work in smaller groups, they would be able to have a more hands-on experience with the lab itself. Also, I don't think that there was any difference in the level of participation of certain students with the inquiry-based lab module versus a traditional lab. Some students will always step up and play an integral role in an experiment and others will take a back seat. While this lab module has been implemented into a first year chemistry course, I think it would be more effective to utilize this experiment in an analytical or upper level chemistry class. More time would be able to be spent going over the instrumentation and explaining the more challenging aspects of electrochemistry.

Currently, new applications and extensions of this lab module are underway which involve sol-gel electrodes and spectroscopic studies done on iridium oxide thin film plates. Engineering new types of sensors with new polymers is another avenue for further development. For the instructor, this module has open-ended possibilities. It has been seen already that, as a consequence, students are attracted to analytical chemistry and to research in electrochemical sensors with Dr. Suzanne Lunsford at Wright State University and Dr. Ted Clark from The Ohio State University. The success of this lab module will hopefully encourage instructors and students alike to become more involved with inquiry-based experiments and bring about a positive change in the way college science courses are taught.

Finally, as with the introduction of any type of new laboratory experiment, the experiences for both the teaching assistants and the students was challenging, frustrating, but also rewarding. I feel that by even just having some students wanting to do research now is a step in the right direction. If nothing else, the students have some idea why learning chemistry, particularly oxidation and reduction reactions, is important. They can make a connection between what they are doing in school and what goes on in the real world. They can see that science does matter.

APPENDIX A

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I liked the objective of this project. I love learning about the nervous system, so this experiment intrigued me.

2. What did you like the *least* about your experience with this REEL project?

I did not like all the initial confusion at the start of this lab. It all worked out in the end though.

3. What would you change or improve in the next implementation of this REEL project?

Nothing I can think of.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

I think it has because now I feel more confident about research.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

Learning about a real-life topic.

2. What did you like the *least* about your experience with this REEL project?

It was way too long and at a level that I didn't understand yet. It was not explained well.

3. What would you change or improve in the next implementation of this REEL project?

Have an overview of what terms meant and what was actually taking place.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

No it has not, I found it to be a bit boring and tedious.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I enjoyed actually working with chemicals that I was told was hazardous.

2. What did you like the *least* about your experience with this REEL project?

Way too many references, the experiment itself was way too repetitive, and boring. I can't speak for everyone but I don't think I was ready for this, needed more of a foundation because a lot of it went over my head very badly. A lot of terminology I'd never heard of before and was very uncomfortable with. So we had to learn way too much of it on our own.

3. What would you change or improve in the next implementation of this REEL project?

Put all the references in either one manual or in a collection so we don't have to look everywhere for them.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Less because I did not enjoy the experience at all. It was all just a great hassle.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

Having multiple sources to reference in order to understand what the lab was supposed to prove. Sometimes the lab manual is so generic, it is not clear what the hypothesis is—and therefore unclear about what the findings should have been.

2. What did you like the *least* about your experience with this REEL project?

It was difficult for me to relate this lab to what I previously studied in chemistry.

3. What would you change or improve in the next implementation of this REEL project?

Smaller groups. Some members contributed absolutely nothing!

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes, but much into the future. The project pointed out what I didn't know.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

The part I liked the most was the making of the solutions because it was really the only part I understood.

2. What did you like the *least* about your experience with this REEL project?

Overall I did not like the experience very much. I felt we were doing things that we did not know enough about. It may have been more enjoyable for a more upper level chemistry class.

3. What would you change or improve in the next implementation of this REEL project?

I would say we should have been given more background information than a confusing packet.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

This project did not increase my interest in pursuing scientific research because it was very frustrating and discouraging most of the time. However, I am sure scientific can be very interesting as well. I would not base my decision on this experiment.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I liked being able to use equipment that undergrads normally aren't allowed to use.

2. What did you like the *least* about your experience with this REEL project?

I didn't feel like there was enough elementary information about the material to do the best job I could.

3. What would you change or improve in the next implementation of this REEL project?

I would take one session just to show students how the machines work and to discuss needed background/elementary information.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes, because it is more hands-on and more challenging than most laboratories conducted in this course.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   How large the groups were. A lot of teamwork was needed to be successful.

2. What did you like the *least* about your experience with this REEL project?

   I did not understand what the cyclic voltameter was showing.

3. What would you change or improve in the next implementation of this REEL project?

   Give a step-by-step procedure instead of just trial & error.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   Not really, it was too stressful.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   How it applied science to our own individual studies.

2. What did you like the *least* about your experience with this REEL project?

   Nothing really.

3. What would you change or improve in the next implementation of this REEL project?

   Having more chemicals on hand instead of rationing what chemicals were left.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   Yes, because some of the things I took from this project helped to better understand the importance of chemistry and how it can be applied to my particular major.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   Working with other students.

2. What did you like the *least* about your experience with this REEL project?

   Too little time with TA to help with experiment—too cluttered.

3. What would you change or improve in the next implementation of this REEL project?

   Explain experiment better.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   Not really.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I like performing an experiment that relates to my future career goal in the health care profession.

2. What did you like the *least* about your experience with this REEL project?

The experiment was so time consuming and frustrating.

3. What would you change or improve in the next implementation of this REEL project?

I would suggest either to not have as many trials for catechol or ascorbic acid, or split the work between groups.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes, participating the REEL project has increased my interest in pursuing undergraduate scientific research because I enjoyed learning about how neurotransmitters applied to something I learned in class, oxidation and reduction reactions.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I liked working with such advanced technology. The equipment used as well as the experiment itself were of great interest to me. I also liked working with a group rather than just one lab partner. It was helpful to learn and discuss ideas with each other.

2. What did you like the *least* about your experience with this REEL project?

The experiment was very time consuming. It was frustrating to make all the solutions and then get no results from them and have to start again. Then again, that is what happens in science.

3. What would you change or improve in the next implementation of this REEL project?

I thought the experiment in itself was good. My only complaint was the room we were in was very crowded. It was hard to move around and concentrate.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes. The experiment was related to real world situations that are directed towards my major so it was something I would do again.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I liked the opportunity to work with equipment I have never even heard of prior to the lab.

2. What did you like the *least* about your experience with this REEL project?

My exposure to the type of experiment before we actually started the lab. I felt ill-prepared for the lab.

3. What would you change or improve in the next implementation of this REEL project?

I would teach students more about the experiment at hand before jumping into it, make sure they feel comfortable with proceeding with the lab.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes, it is interesting to work with experiments that can actually help people.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I liked that the experiments we were running were related to new and exciting medical research.

2. What did you like the *least* about your experience with this REEL project?

I would have liked to be better educated on the software and hardware used for the experiment.

3. What would you change or improve in the next implementation of this REEL project?

Perhaps, extend this experiment a week longer, and use the additional time to explain/show students how to use the software/hardware and the importance of correctly making the solutions needed.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes it has increased my interest because it sort of took away some of the mystery involved in "scientific research".

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   Gaining knowledge in electrochemistry.

2. What did you like the *least* about your experience with this REEL project?

   Too many students in a group.

3. What would you change or improve in the next implementation of this REEL project?

   To go over language used.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   Yes, it was exciting to be a part of.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

Getting the chance to use new equipment and understand/experience real world application to our class material.

2. What did you like the *least* about your experience with this REEL project?

The setting where our experiment took place was crowded/unorganized. The handouts were given to us to use but did not help us understand it by just giving it without thorough explanation by the teacher.

3. What would you change or improve in the next implementation of this REEL project?

Give students more weeks to complete the project. Also take time out for the TA to explain what each terminology means and the data needed to input into computer.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes, due to the fact that after all is said and done. Provided that my classmates and I were given more time in the week to understand and read the project. I now have a better appreciation for the work my group accomplished on this REEL project. I'm proud to have been a part of REEL because I have discovered a connection to Chem 123 & my future in research.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

2. What did you like the *least* about your experience with this REEL project?

   Very confusing.

3. What would you change or improve in the next implementation of this REEL project?

   More pre-lab instructions, not just reading material.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   No, it was kind of a pain and time consuming and not very interesting to me. Might be good for someone going on for masters.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

What I liked most about the experiment is the that the experiment was real.

2. What did you like the *least* about your experience with this REEL project?

It was very time consuming and it took a lot of time to get a good reading.

3. What would you change or improve in the next implementation of this REEL project?

Sometimes the directions on what we were going to do next were unclear and confusing.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

I would love to participate in undergraduate research if there were projects that were available.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

It was a great experiment for a real world experience in electrochemistry.

2. What did you like the *least* about your experience with this REEL project?

I thought that the project was a little unorganized and the initial explanation was a little unclear.

3. What would you change or improve in the next implementation of this REEL project?

A manual or packet explaining a little more clearly what the different steps in setting up & running the software.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes. Because I am interested in brain chemicals & function.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

It was challenging but rewarding!

2. What did you like the *least* about your experience with this REEL project?

We weren't very educated prior to this experiment. (The technology was very foreign)

3. What would you change or improve in the next implementation of this REEL project?

If we could learn more about the technology before the lab, it would be nice!

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes! It was fun!

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I liked this project because it gave me some real insight on what a job as a scientist. It was an experience that showed me what research was like and how it was done on a small scale.

2. What did you like the *least* about your experience with this REEL project?

I found it difficult to duplicate the exact results that we were supposed to replicate. I couldn't figure out what the problem was.

3. What would you change or improve in the next implementation of this REEL project?

I don't think I would change anything except maybe having more cleaning solution.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

I think that it has given me some interest in undergraduate research because I want to experience it first hand. I have seen a little and now I am curious as to what it might entail.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

That it had real world applications.

2. What did you like the *least* about your experience with this REEL project?

For the lab we should have signed up in time slots because the TA didn't have enough time to answer everyone's questions & help. Also the room was very small w/ large groups.

3. What would you change or improve in the next implementation of this REEL project?

Depending on the facilities make smaller groups and have students sign up. Because this is a grad. level lab we need more one on one time.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes, I was planning on doing graduate research anyway and this has enhanced my drive to achieve that goal.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   It related to REEL life.

2. What did you like the *least* about your experience with this REEL project?

   It went on a bit long.

3. What would you change or improve in the next implementation of this REEL project?

   Make sure materials are clean and you know where they are ahead of time.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

It seems neat if you're interested in this sort of thing, but I am not, however the research is intriguing.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

    The making of solutions.

2. What did you like the *least* about your experience with this REEL project?

    That our solutions were duds.

3. What would you change or improve in the next implementation of this REEL project?

    Bigger lab.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

    Not particularly, only because it's not my area of interest anyway.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

2. What did you like the *least* about your experience with this REEL project?

3. What would you change or improve in the next implementation of this REEL project?

    We need more information to understand what this lab is about.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

    No, actually I don't understand why we need this lab.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   Learning about a cause of Parkinson's disease.

2. What did you like the *least* about your experience with this REEL project?

   The speed of introduction.

3. What would you change or improve in the next implementation of this REEL project?

   Felt a bit rushed.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   A little bit, it is interesting to discover a way to detect possible causes of diseases.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   The computer graphs.

2. What did you like the *least* about your experience with this REEL project?

   I didn't understand half of what was going on.

3. What would you change or improve in the next implementation of this REEL project?

   More background information.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   No, I don't want to do research.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

Getting to see the polymer grow and doing something out of the standard book material.

2. What did you like the *least* about your experience with this REEL project?

It was kind of confusing.

3. What would you change or improve in the next implementation of this REEL project?

More pre-lab information.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Not really increased it. I just generally don't like labs.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   It definitely opened my eyes more to the practical application of chemistry.

2. What did you like the *least* about your experience with this REEL project?

   All the lab concepts were a little over my head.

3. What would you change or improve in the next implementation of this REEL project?

   I would do a demonstration in the lab first.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   Not really. I don't have much interest in research at the moment.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

Getting to see how important a role computers play in chemical analysis.

2. What did you like the *least* about your experience with this REEL project?

Not as hands–on as I had hoped due to the size of the group.

3. What would you change or improve in the next implementation of this REEL project?

A longer recitation/more explanation.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes. I would like to know how to use computers w/ scientific programs & apply things I have learned.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   Helping to make the solutions.

2. What did you like the *least* about your experience with this REEL project?

   Solutions didn't work.

3. What would you change or improve in the next implementation of this REEL project?

   More time to understand the concepts and see successful results.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   Yes, because it allowed me to see how the research applies to real life issues.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

I think it was really interesting! I have never done anything like this before.

2. What did you like the *least* about your experience with this REEL project?

The lab room was too small! A bigger one should be given to use.

3. What would you change or improve in the next implementation of this REEL project?

Try to get more students involved to see the experiment, and if possible allow for more hands-on.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

I can't say that it has geared me towards undergraduate research, but it hasn't scared me away!

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

   Observing the oxidation & reduction peaks.

2. What did you like the *least* about your experience with this REEL project?

   Not enough time...

3. What would you change or improve in the next implementation of this REEL project?

   Make this longer (2 week lab).

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

   Yes—it's very interesting.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

    The application to medicine/bio.

2. What did you like the *least* about your experience with this REEL project?

    It was a bit over my head.

3. What would you change or improve in the next implementation of this REEL project?

    It was a lot to handle for me.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

    Yes, I liked the integration of different scientific disciplines.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

Hands-on experiences in the lab.

2. What did you like the *least* about your experience with this REEL project?

The reading material was very difficult compared to our usual lab experiments.

3. What would you change or improve in the next implementation of this REEL project?

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Maybe—I was already interested in undergrad research—especially in biology—but not really aware of opportunities to do so.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

The fact that I was introduced to something I previously had no knowledge existed was a great experience. I never even heard of the chemical catechol, so to work with it was nice.

2. What did you like the *least* about your experience with this REEL project?

The lab was kind of mind blowing and seemed very confusing at times. However, if it was more organized it could have been a very beneficial lab.

3. What would you change or improve in the next implementation of this REEL project?

The only thing I would change about the REEL project is to make the lab more organized. I felt very lost at times throughout the lab.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes. I was already interested in scientific research and this increased my interests. I liked this particular scientific research because it has something to do with the human body.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

    Real life application.

2. What did you like the *least* about your experience with this REEL project?

    Closed quarters, little hands on.

3. What would you change or improve in the next implementation of this REEL project?

    Bigger lab. More preparation so I'm not so overwhelmed.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

    No, I'm a bio major.

REEL—Post Project Survey

Please answer the following questions in order to help us improve the future implementations of the NSF-supported OCUR—REEL (Ohio Consortium for Undergraduate Research—Research Experiences to Enhance Learning) Project.

1. What did you like the *most* about your experience with this REEL project?

The practical applications of the experiment. I also liked the challenge of the experiment.

2. What did you like the *least* about your experience with this REEL project?

The lack of equipment per size of the class.

3. What would you change or improve in the next implementation of this REEL project?

Less students per equipment.

4. Has participation in this REEL project increased your interest in pursuing undergraduate research? Why or why not?

Yes. Undergraduate study does not have to be mundane recitation of textbook and lecture material. Challenging experiments and innovative study make undergraduate work more interesting and a better learning experience.

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